Published in final edited form as:
Neuroimage. 2010 February 1; 49(3): 2687. doi:10.1016/j.neuroimage.2009.10.070.

Neural Mechanisms of the Influence of Popularity on Adolescent Ratings of Music

Gregory S. Berns[1,2], **C. Monica Capra**[2], **Sara Moore**[1], and **Charles Noussair**[2,3]

[1] Department of Psychiatry & Behavioral Sciences, Emory University School of Medicine, Atlanta, GA [2] Economics Department, Emory University, Atlanta, GA [3] Department of Economics, Tilburg University, Tilburg, The Netherlands

Abstract

It is well-known that social influences affect consumption decisions. We used functional magnetic resonance imaging (fMRI) to elucidate the neural mechanisms associated with social influence with regard to a common consumer good: music. Our study population was adolescents, age 12–17. Music is a common purchase in this age group, and it is widely believed that adolescent behavior is influenced by perceptions of popularity in their reference group. Using 15-second clips of songs from MySpace.com, we obtained behavioral measures of preferences and neurobiological responses to the songs. The data were gathered with, and without, the overall popularity of the song revealed. Song popularity had a significant effect on the participants' likability ratings of the songs. fMRI results showed a strong correlation between the participants' rating and activity in the caudate nucleus, a region previously implicated in reward-driven actions. The tendency to change one's evaluation of a song was positively correlated with activation in the anterior insula and anterior cingulate, two regions that are associated with physiological arousal and negative affective states. Sensitivity to popularity was linked to lower activation levels in the middle temporal gyrus, suggesting a lower depth of musical semantic processing. Our results suggest that a principal mechanism whereby popularity ratings affect consumer choice is through the anxiety generated by the mismatch between one's own preferences and others'. This mismatch anxiety motivates people to switch their choices in the direction of the consensus. Our data suggest that this is a major force behind the conformity observed in music tastes in some teenagers.

INTRODUCTION

It is well-known that social influences affect consumption decisions. In particular, a consumer's tendency to purchase a product is influenced by the choices made by his associative reference group (Bearden and Rose, 1990; Childers and Rao, 1992; Escalas and Bettman, 2005; Lascu and Zinkhan, 1999). Why do the actions of others affect a person's decisions? Following the pioneering work of Solomon Ash (Asch, 1951, 1952), social psychologists have identified several reasons. These include the desire to avoid social sanctions, the need to comply with a perceived request, and simply the drive to conform. With respect to the last reason, empirical research supports the conceptual distinction between informative and normative motivations

Correspondence: Gregory S. Berns, Department of Psychiatry & Behavioral Sciences, Emory University School of Medicine, 101 Woodruff Circle, Suite 4000, Atlanta, GA 30322, Phone: (404) 727-2556, Fax: (404) 727-3233 gberns@emory.edu.

to conform (Deutsch and Gerard, 1955), which translate roughly to the desire to behave accurately versus the desire to behave correctly in a social sense (Cialdini and Goldstein, 2004). On the other hand, it is also possible that information about the decisions of one's reference group influences one's actual preferences about the product. That is, observing others' choice of an item changes the intrinsic value that one attaches to that item. Indeed, there is evidence that preferences are susceptible to various influences such as the way information is provided or framed. This is consistent with the suggestion that preferences are not stable, but rather are constructed during a decision situation (Ariely et al., 2006; Bettman et al., 1998; Slovic, 1995). Thus, the mechanism whereby social influence affects purchasing decisions may be purely in altering actions (due to informational or normative reasons) without exercising any effect on underlying preferences, or alternatively, it may be through an effect on preferences themselves.

In this paper we are particularly interested in identifying the mechanism whereby social information affects consumption decisions. Although several experiments have been designed to disaggregate the informational and normative motives to conform (Capra and Li, 2008; Carpenter, 2004; Cason and Mui, 1998) few people have studied the extent to which conformity is generated by changes in preferences (a recent exception in economics is Cooper and Rege, 2008). One problem is that informational, normative, and preferential processes may all be at work in specific situations, and the influence of each element may be difficult to isolate by only measuring decisions, even in controlled behavioral experiments.

One method of bypassing this problem is to use brain imaging. This allows researchers to directly measure neurological activation during a decision task. The rapid evolution of the field of neuroeconomics has resulted in a wealth of data about distinct brain systems involved in elements of individual choice (see, for example, Rangel et al., 2008). Based on these data, some consensus has arisen about the functions of different regions of the brain. For example, convergent evidence from these studies points to activation in dopaminergic receptive regions as associated with value (Camerer et al., 2005; Glimcher et al., 2005; Hampton and O'Doherty, 2007; Knutson et al., 2007; Knutson et al., 2005; Montague and Berns, 2002). Similarly, the activation of the insula has been associated with aversive states (Berns et al., 2008; Berns et al., 2006; Chandrasekhar et al., 2008; Craig, 2003; Koyama et al., 2005; Peyron et al., 2000; Ploghaus et al., 2003; Porro et al., 2002). In contrast, there is less consensus about the neural mechanisms of social influence. However, using current knowledge of how the brain processes reward, it is possible to utilize fMRI technology to discriminate between conformity that is merely in actions, and thus presumably motivated by the discomfort of being different, and conformity that is generated by changes in valuation (see, for example, Berns et al., 2005 or Klucharev et al., 2009).

Here, we study the effect of social influence by considering how information about the popularity ratings of particular songs influences an individual's own evaluation of the songs. In our experiment, participants were asked to rate songs according to their own preference before and after observing a rating of how popular the song was among a large reference group. To generate incentives to evaluate different songs in accordance with one's willingness to purchase the product, participants received a CD with the music they rated most highly at the end of the session. The use of music as the consumption good for the experiment has the methodological advantage that it can be easily delivered and consumed while the subject is being scanned. We chose adolescents from the ages of 12 to 17 as our subject pool for two reasons. The first is that this cohort of people is believed to be highly responsive to social influence (Steinberg and Monahan, 2007). The second is that consumers in this age group are typically consumers of music, responsible for more than one third of all single album consumption in the United States and perhaps a greater proportion when online digital purchases are included. We choose popularity ratings as our measure of group opinion for two reasons. First, ratings for music are widely present on the internet, and thus likely to be a familiar medium of information transmission for our participants. Second, ratings provide a simple numerical measure of the degree of conformity. We measure whether providing popularity rating information results in individuals changing their ratings in the direction of the popularity rating. We then investigate, using brain imaging, the mechanism underlying any such effect we observe. A priori, we believed that the design choices of music and popularity ratings for our experiment meant that there was scope for ratings to change because of both a drive to match ratings to a popular view, as well as an actual change of an individual's intrinsic valuation. We use brain imaging to distinguish between these forces and to advance claims about which force is at work in our experiment.

Behaviorally, we find that the observation of popularity ratings does affect the individuals' ratings for songs, and individuals tend to adjust their ratings to make them more consistent with the population. In addition, we find that activation in the left and right anterior insula at the time an individual is informed about the popular opinion is significantly associated with his tendency to change his/her ratings in response to the popularity information. Because insula activation tends to be associated with a state of physiological arousal (Craig, 2002), our results suggest that a principal mechanism by which popularity ratings affect adolescent consumer choice is through the anxiety generated by the mismatch between one's preferences and others'. This mismatch anxiety appears to motivate adolescents to switch their choices in the direction of the popularity rating, suggesting that this type of mismatch is a major force behind conformity observed in music tastes in teenagers. Because activation in regions traditionally associated with value are not affected by popularity information, it seems that at least in our specific context, changes in preference for the product itself do not play a major role in explaining conformity.

MATERIALS AND METHODS

General setting

A total of 32 participants were studied. Five were excluded from the fMRI analyses due to either excessive movement or susceptibility artifacts. Although this was a relatively high exclusion rate compared to adult studies, it was comparable to previous fMRI studies in children and adolescents, who tend to move more than adults (Galvan et al., 2006). Prior to the experiment, they were screened for the presence of medical and psychiatric diagnoses, and none were taking medications. There were 14 female and 13 male participants between the ages of 12 and 17.9 (mean 14.6). Fifteen were Caucasian, 8 were African-American, 1 was Hispanic, and 3 were "Other."

The primary stimuli used were 15-second clips from songs downloaded from MySpace.com. Songs were downloaded between October 23 and November 8, 2006. In order to minimize the possibility that participants would recognize the artists, only songs from unsigned musicians were used. A total of 20 songs were downloaded in each of the following genres: Rock, Country, Alternative/Emo/Indie, Hip-Hop/Rap, Jazz/Blues, and Metal (identified by the MySpace category).

At the time of download, the number of times each song had been played was recorded, and this was used to calculate the popularity of each song among MySpace users. The number of plays ranged from 876 to 1,998,147. To put these numbers in some perspective, as of September 2009, song-plays by top signed-artists approach 100,000,000. The popularity of each song was calculated by determining the Z-score of each song and binning the Z-scores into quintiles, resulting in popularity scores that ranged from 1–5. This procedure was explained to each subject before the experiment. Each song was converted from MP3 to WAV format and a 15-

second clip was extracted that included either the hook or chorus of the song. These 15-second clips were subsequently used in the experiment.

Timing within experimental sessions

At the beginning of each session, individuals' rankings of musical genres were elicited. Participants were provided with a list of the six musical genres, and were instructed to rank the genres from 1 ("the type you like the best") to 6 ("the type you like the least.") Each participant's top three genres were subsequently used in the experiment. After taking a urine test to screen for illicit substance abuse and pregnancy, subjects completed a Childhood Depression Inventory. This inventory was used to screen out subjects who might be depressed. No subject met the exclusion criterion of a T-score greater than 70 (clinically depressed). Next, they completed the Adolescent Risk Questionnaire, which is a 22-item survey of activities such as drinking and driving, driving without a license, having unprotected sex, and taking drugs (Gullone et al., 2000). Following this, they completed a Gambling Task developed by Harbaugh, Krause, and Vesterlund (Harbaugh et al., 2002), where individuals engaged in a series of gambles for money, and then completed the WASI IQ test. Emory University's Institutional Review Board approved all procedures.

Individuals then entered the scanner, and the total scan time was approximately 1 hour. The scanning was performed on a Siemens 3T Trio. Each subject received a T1-weighted structural image (TR = 2600 ms, TE = 3.93 ms, flip angle = 8, 224×256 matrix, 176 sagittal slices, 1 mm cubic voxel size), a DTI scan (TR = 6500 ms, TE = 90 ms, flip angle = 90, FOV = 220mm, 128×128 matrix, 34 axial slices, 1.7×1.7×2.5mm voxel size, 6 sets of 12 directional b = 1000 and 1 b = 0 images), and 3 functional runs of BOLD-weighting (TR = 2000 ms, TE = 31 ms, flip angle = 90, FOV = 192mm, 64×64 matrix, 28 axial slices, 3 mm cubic voxel size). Each individual participated in 60 trials. The sequence of events in each trial is illustrated in figure 1. Each trial was divided into two stages; in each stage the subject listened to the same 15-second song clip. During stage one, no popularity information was shown. After listening, subjects were required to rate the song based on (a) how familiar it was and (b) how much they liked it. Both ratings used a 1–5 star scaling system. To prevent the subject from passively accepting a default rating, each rating screen began with 0 stars, which could not be accepted as a final selection. After the rating was entered, stage two of the trial took place. The clip was played again, after which the subject provided another likability rating. Twenty songs in each of the subject's top-three genres were presented in random order throughout the experiment. In 2/3 of the trials, during the second listen, the song's popularity was displayed in the 1–5 star scaling system. The 40 trials in which the popularity display appeared were sequenced randomly among the 60 trials. As an incentive to accurately reveal their song preferences, each subject received a CD with their top-rated songs.

Analysis

In order to quantify the effect of popularity on an individual's rating of songs, the regression model in equation (1) was estimated using the data from the 40 trials where the popularity was revealed. In our specification, the change in likability rating between the first and second listening was formulated as a linear function of the difference between popularity and the first likability rating:

$$(lik2_{ij} - lik1_{ij}) = \beta_j (pop_i - lik1_{ij}) + \varepsilon_{ij} \tag{1}$$

where $lik1_{ij}$ and $lik2_{ij}$ are the first and second ratings respectively for subject j on trial i, pop_i is the popularity of the song, β_j is the regression coefficient that measures the propensity of popularity information to change the rating between the first and the second listens. A β=1 would represent complete conformity to popularity ratings and β=0 would indicate no responsiveness to the popularity information. A mixed-model linear regression was performed at the individual subject level. The regression coefficients for each subject gave us a measure of conformity or popularity sensitivity for later incorporation in the fMRI model. These individual estimates were also used to estimate the aggregate effect of popularity information.

The analysis of the fMRI data was conducted in the following manner. Preprocessing of the fMRI data was executed in SPM5 (Functional Imaging Laboratory, UCL, London). The preprocessing pipeline consisted of slice timing correction, motion correction, spatial normalization, and smoothing (with an 8mm Gaussian kernel). A first-level GLM, also constructed in SPM5, contained a maximum of 9 conditions for each of the 27 participants (because some people did not have *listen2pop* × rating change for some/all runs if the column was all zeroes, indicating no rating changes for that run). The first listen of each trial was a 15 s variable duration event with one parametric modulator: the participant's likability rating ($lik1_{ij}$) after listening to the song clip once. The second listen, also a 15 s variable duration event, was classified into one of two conditions based upon whether the popularity was shown (*listen2pop*) or blocked (*listen2nopop*) on that trial. The condition where the popularity was shown (*listen2pop*) was also modulated by: the difference between the popularity rating and stage one rating (pop_i-$lik1_{ij}$), the absolute value of this difference, as well as a binary variable indicating whether the likability rating changed between the first and second listen (*ratechg)*. Two subjects did not have the |*pop-lik1*| modulator for one or more runs because it was a duplicate of (*pop-lik1*). The condition where popularity was blocked (*listen2nopop*) was modulated by the second likability rating only ($lik2_{ij}$). All three variable duration rating phases of the trial (familiarity, first likability, and second likability) were collapsed into one condition with no parametric modulators to model the act of rating including the button presses. The motion parameters were also included in the model as an effect of non-interest.

The following second-level models were constructed as one-sample t-tests in SPM5 using contrast images from the first-level model above. The first model simply included the effect of the first listen, both as a main effect and as parametrically modulated by the first likability rating. The main effect identified brain regions that responded to the music clips relative to the implicit baseline of doing nothing. The likability modulator identified regions in which the amplitude of activity during the first listen varied linearly with the subsequent likability rating. To test the hypotheses about popularity, we next examined the main effect of the second listen with popularity shown (*listen2pop*), the contrast between popularity shown and popularity not shown (*listen2pop - listen2nopop*), and *listen2pop* modulated by the covariates: (*pop–lik1*) and | *pop-lik1*|. Both contrasts were examined as main effects and as subjectwise interactions with the conformity parameter β_j derived from the regression in equation 1. The subjectwise interactions identified regions in which activity changes varied in association with the participant's tendency to conform to the popularity ratings.

Finally, a first-level finite impulse response (FIR) model was also used to extract timecourse responses in regions of interest identified by the aforementioned contrasts. The FIR model contained 9 two-second bins for each of three listening conditions: *listen1, listen2pop*, and *listen2nopop*.

RESULTS

Individual Ratings and Social Influence

The mean likability rating was 2.40 (sd 1.15), indicating a wide range of appeal and good use of the full rating scale. The mean familiarity was 2.05 (sd 1.20), indicating that, on average, participants did not recognize the songs. There was, however, a positive correlation between likability and familiarity (R^2=0.274, P<0.001, 31 d.f.). The two panels of Figure 2 illustrate the percentage of individuals who changed their ratings between the first and second listens. The popularity information had a significant effect on participants' ratings of how much they liked the songs. The upper panel of the figure shows that when no popularity information was given, participants changed their ratings in 11.6% of the trials. However, when popularity was shown, they changed their ratings 21.9% of the time (P=0.0006, paired t-test, 31 d.f.). The lower panel in the figure displays the percentage of time (out of the trials in which the rating was changed) that the rating was changed in the direction of the popularity. Conditional on a change in rating, it was in the direction of the observed popularity rating 38.3% of the time when the rating was not displayed versus 79.9% of the time when the popularity was shown (P<0.00001). The figure clearly shows that the popularity rating influenced individual ratings.

To measure the effects of popularity on the music ratings, we estimated equation (1) for each participant in all trials in which popularity was observed. When the model was estimated at the individual level, individual subject β's ranged from 0 to 0.5, with a mean of 0.15 [se=0.02], suggesting that the tendency to conform varied across the participants but that there was a statistically significant tendency to change the rating between the first and second listening in the direction of the popularity information [$t(31)=6.96$, $P<0.00001$].

Next, we considered the relationship of individual popularity sensitivity (β_j) to decision time during the likability rating. We hypothesized that participants who were more sensitive to popularity (higher estimated β_j) should take longer to make their ratings when popularity was present. Consistent with this hypothesis, there was a significant positive correlation between mean decision time and the subject's popularity sensitivity during the *second* listen (Fig. 3, $R^2 = 0.241$, P=0.009). We did not find a significant correlation during the *first* listen.

We also considered the correlation between the subject variables of gender and age, with the sensitivity of the likability ratings to popularity information (Table 1). Gender was not significantly correlated with the percentage of trials in which the individual changed his/her rating in the direction of the observed popularity rating. However, age did exhibit a significant correlation, with younger subjects changing their ratings more frequently [R = ?−0.407, P=0.02]. Additionally, the popularity sensitivity was negatively correlated with the total score on the Adolescent Risk Questionnaire (ARQ) [R = −0.349, P=0.05], and with the percentage of risky choices in the Harbaugh gambling task for gains [R = −0.356, P=0.045].

fMRI Results

Figure 4 illustrates the regions of the brain that activated in response to the first listening of all musical stimuli. Music elicited activation in a broad network of brain regions associated with auditory and visual sensory processes. These included bilateral superior and middle temporal gyri (auditory cortex), occipital cortex (visual cortex), superior parietal cortex (multimodal sensory integration regions), thalamus, and basal ganglia (caudate nucleus and putamen). The activity in these regions was in comparison to the implicit baseline of no stimulation and was previously expected to yield a broad pattern of activity. In contrast, the correlation of activity during the first listen with the subsequent likability rating revealed a much more restricted network (Table 2). Greater activation was associated with a higher rating for the song. The activation data in the table are from during the first listen, but before the first rating was actually submitted. The regions showing activity correlated with likability were largely distinct from the auditory network and were restricted to bilateral caudate nuclei, and right lateral prefrontal cortices (middle and inferior gyri). Negative correlations with likability were observed in bilateral supramarginal gyri, left insula, and several small frontal regions.

To test the hypothesis that popularity information changes intrinsic preferences, we used the mask generated by the positive correlation of likability with *listen1* (Table 2) to measure the effect of popularity during *listen2*. At the usual threshold of P<0.001, we did not observe any significant positive correlations of activity with *listen2pop* X (*pop-lik1*) within these regions. To guard against type II errors, we relaxed the threshold to P<0.05 but still did not observe any significant positive correlations within these regions. This suggests that the effect of popularity was not exerted through a change in intrinsic preference for the music itself. We did, however, observe correlations of *listen2pop* X (*pop-lik1*) in other regions including occipital cortex, right frontal and ACC (Table 3). Similarly, we found correlations of *listen2pop* X |*pop-lik1*| in regions outside of those identified by the "likability" network. These include significant positive correlations in the left medial PFC and bilateral inferior PFC, and negative correlations in left parietal and temporal regions (Table 4). The binary variable that coded trials during *listen2pop* in which the subject changed her rating was significantly positively correlated with activity only in bilateral middle PFC [MNI coordinates: 51,45,15 (T=4.38, k=8, P<0.001) and −39,30,18 (T=3.72, k=5, P=0.001)]. The only region that was significantly negatively correlated was in the ventral striatum [MNI coordinates: 0,12, −6 (T=3.96, k=8, P<0.001)]. This latter finding means that ventral striatal activity decreased when subjects changed their rating during the second listen (with popularity shown).

As either the informative or normative view of social influence would predict, subjects who displayed behavioral evidence of changing their music ratings in response to popularity information also showed evidence of different neural responses to popularity. The subjectwise sensitivity to popularity exhibited significant interactions with the presence/absence of popularity information during the second listen (Figure 5 & Table 5). Using the difference, [*listen2pop* – *listen2nopop*], and interacting this with the subjectwise popularity sensitivity (β_j), we found a positive interaction in bilateral anterior insula, ACC/SMA, and frontal poles. Given the known roles of the anterior insula and ACC in the cortical pain matrix, this suggests that feelings of anxiety accompanied the act of conforming. Further examination of this interaction showed that much of the effect was driven by the subjectwise differences in activation to *listen2pop* (Figure 6 & Table 6). Interestingly, the negative interaction, *listen2pop* X β_j, revealed significant differences in the middle temporal gyrus. Timecourse extraction showed a sustained activation during the listening period consistent with auditory processing, but the popularity-sensitive individuals showed significantly less activation. This suggests that sensitivity to popularity is also linked to less active listening.

DISCUSSION

To our knowledge, this is the first neuroimaging study of the effect of popularity on the preference for a consumer good. Previous studies of conformity have focused on perceptual effects (Berns et al., 2005) and judgments of facial attractiveness (Klucharev et al., 2009). One candidate explanation for why popularity information affects consumer decisions is that popularity changes the intrinsic value of the consumption good at the most basic level. This would be analogous to the effect which has been observed for market price information (Plassmann et al., 2008). If popularity changed intrinsic preferences, this would presumably occur via a mechanism operating directly on reward pathways in either the orbitofrontal cortex or striatal systems. For example, using sips of wine as a stimulus, while manipulating the "retail" price, Plassmann et al. (Plassmann et al., 2008) observed increased activity in the orbitofrontal cortex when the price was higher. The orbitofrontal cortex is a region of the brain that has been frequently associated with both hedonic (experienced) pleasure and expected economic value (Padoa-Schioppa and Assad, 2006; Roesch et al., 2006; Rolls, 2000; Tremblay and Schultz, 1999). A second possible mechanism, and one for which we find evidence in this study, is that the resolution of personal preference with a consensus opinion invokes a different set of cognitive and emotional processes outside the reward/utility system in the brain. The bilateral insula activation we observed suggests that the latter mechanism was at work, at least for the specific population, social information, and consumption good we consider here.

The effect of music on the brain spans several different brain regions and cognitive systems. Not surprisingly, the primary effect is on the auditory cortex, located around Heschl's gyrus in the superior temporal lobes. Consistent with previous studies of music stimuli, we observed the largest activations in these regions (Janata et al., 2002; Koelsch, 2005; Koelsch et al., 2005; Sridharan et al., 2007). Beyond the raw effect of auditory stimulation, music invokes semantic processes such as whether the musical phrases make sense, and language processes for lyrical content (Levitin and Menon, 2003). These cognitive functions are notably more complex than simple auditory processing and have been associated with activity in language regions of the lateral prefrontal cortex. We also observed this activation as a main effect of the stimulus (Koelsch, 2005; Koelsch et al., 2005). Finally, we found activity of motor and premotor regions of the cortex. As others have noted, the perception of music is, in part, linked to the production of music (e.g. singing or tapping along), and it is common to observe a coupling between auditory streams and motor streams when listening to music (Grahn and Brett, 2007; Lahav et al., 2007; Zatorre et al., 2007).

Compared to the main effect of listening to music, which resulted in multiple activations across different cortical systems, we observed a highly restricted network of regions that correlated with the rating assigned to the individual songs. The strongest correlations were observed in the head of the caudate nucleus bilaterally. This region of the caudate nucleus receives a dense dopaminergic projection from brainstem nuclei and is widely viewed as playing a key role in reward and valuation. The precise nature of this role is still debated (e.g. experienced utility or hedonic pleasure, decision utility, reward-prediction error), but its role in value-based decision making appears well-established (Camerer et al., 2005; Glimcher et al., 2005; Hampton and O'Doherty, 2007; Knutson et al., 2007; Knutson et al., 2005; Montague and Berns, 2002). It is worth noting, however, that previous imaging studies have identified the same region as correlating with intensely pleasurable musical experiences (Blood and Zatorre, 2001; Koelsch et al., 2006), which suggests that experienced utility is likely a significant component of the striatal response to music. In our study, the pattern is clear: the higher the individual rated a particular song, the greater the activity in the caudate nucleus. This correlation does not appear to be related to familiarity.

To test the hypothesis that popularity information changes instrinsic preferences, we used the regional pattern identified by the correlation of *listen1* with *lik1* as a mask for several contrasts during *listen2pop*. The rationale behind this approach is that if popularity modulates preference, it should manifest itself within the network of brain regions that correlate with song likability. However, within these regions we did observe any significant correlation with the contrast, (*pop-lik1*), even at a threshold of $P<0.05$. Similarly, there were no significant correlations with the contrast of the absolute value of this difference, |*pop-lik1*|. We did observe correlations outside of the "likability" network, suggesting that popularity did exert a significant brain response, but their locations were not consistent with changing intrinsic preferences for the music itself. The only significant popularity-related effect within the orbitofrontal-striatal network was when the subject changed his rating. Regardless of the direction of the rating change, this was associated with less activity in the ventral striatum. With the usual caveats about reverse inference (Poldrack, 2006), and to the extent that ventral striatal activity is reward-related, this decrement is suggestive of some type of personal cost when the subject changes his rating.

Consistent with this potentially costly effect of popularity information, we found significant effects in the anterior insula (bilaterally) and ACC when we included subject-specific measures of popularity-sensitivity (Table 5 and Fig. 5). These regions are typically associated with internal arousal states, frequently observed during the anticipation and experience of noxious stimuli (Berns et al., 2008;Berns et al., 2006;Chandrasekhar et al., 2008;Craig, 2003;Koyama et al., 2005;Peyron et al., 2000;Ploghaus et al., 2003;Porro et al., 2002). Activation of the insula has also been associated with processing of financial risk (Preuschoff et al., 2006) as well as social signals like empathic responses to pain in others (Singer et al., 2004). Importantly, the individuals who exhibited the most sensitivity to popularity in their behavior were those individuals who had the largest responses to popularity in their insula. Insula activation is sometimes observed in states of positive arousal, but the decrease in ventral striatal activity when subjects changed their ratings, coupled with insula/ACC correlations with the subjectwise popularity-sensitivity, suggests that a mismatch between one's rating and others' ratings may trigger a cognitive/emotional dissonance. This dissonance may be more pronounced in some individuals than others. Individuals who exhibit a stronger effect have a greater tendency to change their choices.

Although we did not obtain self-reported measures of anxiety from the participants, the correlations of popularity-sensitivity with other demographic and behavioral measures points towards a dissonance mechanism. We found significant negative correlations of popularity sensitivity with age, engagement in risky activities on the Adolescent Risk Questionnaire (ARQ), and lottery preferences on the Harbaugh gambling task. Although age and ARQ are positively correlated with each other, the direction of these correlations shows that the participants who were most influenced by the music popularity ratings were relatively young, did not engage in drinking/drugs/sex, and were risk-averse over financial gains. The consistent direction of these correlations suggests that these subjects were more risk-averse across a variety of domains. This risk aversion may lead an individual to refrain from high-risk/high sensation teen activities like sex and drugs, while simultaneously being averse to financial gambles, and also being sensitive to behaving differently than what is considered popular. Indeed, the confluence of findings paints a picture of an anxious type of person. This interpretation is also consistent with a growing body of data that implicate the anterior insula in interoceptive processing, especially in the presence of threatening stimuli (Craig, 2002; Critchley et al., 2004).

Although there are very few imaging studies of conformity per se, our results seem, in part, consistent with others' findings. In a previous study, our group found evidence for conformity-related activity changes in occipital and parietal areas during a task of mental rotation, but we also found activation of the amygdala when individuals went against the group opinion (Berns et al., 2005). This study was quite different in both the task and the incentives, yet the amygdala is another key structure in the arousal circuits of the brain. Anterior insula activation has also been associated with Machiavellian personality traits when social norms are enforced by the threat of punishment during a financial transfer game (Spitzer et al., 2007), and when subjects received unfair offers during the ultimatum game (Sanfey et al., 2004). In addition, ACC activity was greater in individuals sensitive to popularity in our study. ACC activation has also been observed in prior studies in individuals who experience social exclusion in a ball-tossing game (Eisenberger et al., 2003) and in a study of neural responses to conformity and facial attractiveness (Klucharev et al., 2009). This last result was interpreted as representing the conflict between individual and group opinion. Such a conflict could also explain our findings if subjects found it distressing to conform to popular opinion. Unlike Klucharev et al., however, we did not observe ACC correlation with the contrast *listen2pop x |pop-lik1|*, which may reflect differences in the medium of decision making (faces vs. music) or that our task was anchored in a consumption decision for music (i.e. incentive compatibility), or that the ACC response was present only in subjects who were sensitive to popularity information.

Our finding that popularity is not associated with striatal activation suggests that music popularity ratings do not affect adolescents' preferences over music (if striatal activitation can be interpreted as representing reward value). Clearly, we do not know whether a lack of a preference effect would be carried over to different consumption goods and age cohorts. However, based on our study and previous research mentioned above, it seems that one mechanism by which social influence affects behavior is through generating mismatch anxiety. The mechanism may be operative and influence behavior in a broad class of environments. There are at least two interesting implications of our neurobiological study of conformity that we believe may help economists in formulating models of conformity. The first is that mimicking others seems to be, at least in part, motivated by the need to avoid the disutility from being a contrarian rather than by the pursuit of a positive utility from doing the same thing as others. The second is that anxiety associated with conformity is a cost that perhaps economists should take into account when performing welfare calculations.

Finally, we found significantly lower levels of activation in the middle temporal gyrus of subjects who were sensitive to the popularity information. The timecourse of activity in this region showed a sustained activation during the song and strongly suggests a musical semantic process (Koelsch, 2005). Conformists had lower activity across the whole song period relative to non-conformists, indicating that their sensitivity to popularity was also related to the degree to which they may have paid attention to the musical semantics of the song itself, which includes chord progressions, rhythm and lyrics.

Acknowledgments

We are grateful to the National Institute on Drug Abuse (NIDA) for grant support of this project (R01 DA016434 and R01 DA20116 to G.S.B.).

References

Ariely D, Loewenstein G, Prelec D. Tom Sawyer and the construction of value. Journal of Economic Behavior and Organization 2006;60:1–10.

Asch, SE. Effects of group pressure upon the modification and distortion of judgements. In: Guetzkow, HS., editor. Groups, Leadership and Men. Research in Human Relations. Carnegie Press; Pittsburgh: 1951. p. 177-190.

Asch, SE. Social Psychology. Prentice-Hall, Inc; New York: 1952.

Bearden WO, Rose RL. Attention to social comparison information: an individual difference factor affecting consumer conformity. Journal of Consumer Research 1990;16:461–471.

Berns GS, Capra CM, Chappelow J, Moore S, Noussair C. Nonlinear neurobiological probability weighting functions for aversive outcomes. NeuroImage 2008;39:2047–2057. [PubMed: 18060809]

Berns GS, Chappelow JC, Cekic M, Zink CF, Pagnoni G, Martin-Skurski ME. Neurobiological substrates of dread. Science 2006;312:754–758. [PubMed: 16675703]

Berns GS, Chappelow JC, Zink CF, Pagnoni G, Martin-Skurski ME, Richards J. Neurobiological correlates of social conformity and independence during mental rotation. Biol Psychiatry 2005;58:245–253. [PubMed: 15978553]

Bettman RJ, Luce MF, Payne JW. Constructive consumer choice processes. Journal of Consumer Research 1998;25:187–217.

Blood AJ, Zatorre RJ. Intensely pleasurable responses to music correlate with activity in brain regions implicated in reward and emotion. Proc Natl Acad Sci U S A 2001;98:11818–11823. [PubMed: 11573015]

Camerer C, Loewenstein G, Prelec D. Neuroeconomics: how neuroscience can inform economics. Journal of Economic Literature 2005;XLIII:9–64.

Capra CM, Li L. Conformity in contribution games: gender and group effects. Emory University Working Paper. 2008

Carpenter J. When in Rome: conformity and the provision of public goods. Journal of Socioeconomics 2004;33:395–408.

Cason TN, Mui VL. Social influence in the sequential dictator game. Journal of Mathematical Psychology 1998;42:248–265. [PubMed: 9710550]

Chandrasekhar PV, Capra CM, Moore S, Noussair C, Berns GS. Neurobiological regret and rejoice functions for aversive outcomes. NeuroImage 2008;39:1472–1484. [PubMed: 18042401]

Childers T, Rao A. The influence of familial and peer-based reference groups on consumer decisions. Journal of Consumer Research 1992;19:198–211.

Cialdini RB, Goldstein NJ. Social influence: compliance and conformity. Annual Review of Psychology 2004;55:591–621.

Cooper D, Rege M. Social interaction effects and choice under uncertainty: an experimental study. Florida State University Working Paper. 2008

Craig AD. How do you feel? Interoception: the sense of the physiological condition of the body. Nature Reviews Neuroscience 2002;3:655–666.

Craig AD. Pain mechanisms: labeled lines versus convergence in central processing. Annual Review of Neuroscience 2003;26:1–30.

Critchley HD, Wiens S, Rotshtein P, Ohman A, Dolan RJ. Neural systems supporting interoceptive awareness. Nature Neuroscience 2004;7:189–195.

Deutsch M, Gerard HB. A study of normative and informational social influences upon individual judgment. Journal of Abnormal and Social Psychology 1955;51:629–636.

Eisenberger NI, Lieberman MD, Williams KD. Does rejection hurt? An fMRI study of social exclusion. Science 2003;302:290–292. [PubMed: 14551436]

Escalas J, Bettman JR. Self-construal, reference groups, and brand meaning. Journal of Consumer Research 2005;32:378–389.

Galvan A, Hare TA, Parra CE, Penn J, Voss H, Glover G, Casey BJ. Earlier development of the accumbens relative to orbitofrontal cortex might underlie risk-taking behavior in adolescents. J Neurosci 2006;26:6885–6892. [PubMed: 16793895]

Glimcher PW, Dorris MC, Bayer HM. Physiological utility theory and the neuroeconomics of choice. Games and Economic Behavior 2005;52:213–256. [PubMed: 16845435]

Grahn JA, Brett M. Rhythm and beat perception in motor areas of the brain. Journal of Cognitive Neuroscience 2007;19:893–906. [PubMed: 17488212]

Gullone E, Moore S, Moss S, Boyd C. The adolescent risk-taking questionnaire: development and psychometric evaluation. Journal of Adolescent Research 2000;15:231–250.

Hampton AN, O'Doherty JP. Decoding the neural substrates of reward-related decision-making with functional MRI. Proc Natl Acad Sci U S A 2007;104:1377–1382. [PubMed: 17227855]

Harbaugh WT, Krause K, Vesterlund L. Risk attitudes of children and adults: choices over small and large probability gains and losses. Experimental Economics 2002;5:53–84.

Janata P, Birk JL, van Horn JD, Leman M, Tillman B, Bharucha JJ. The cortical topography of tonal structures underlying western music. Science 2002;298:2167–2170. [PubMed: 12481131]

Klucharev V, Hytönen K, Rijpkema M, Smidts A, Fernández G. Reinforcement learning signal predicts social conformity. Neuron 2009;61:140–151. [PubMed: 19146819]

Knutson B, Rick S, Wimmer GE, Prelec D, Loewenstein G. Neural predictors of purchases. Neuron 2007;53:147–156. [PubMed: 17196537]

Knutson B, Taylor J, Kaufman M, Peterson R, Glover G. Distributed neural representation of expected value. Journal of Neuroscience 2005;25:4806–4812. [PubMed: 15888656]

Koelsch S. Neural substrates of processing syntax and semantics in music. Current Opinion in Neurobiology 2005;15:207–212. [PubMed: 15831404]

Koelsch S, Fritz T, Schulze K, Alsop D, Schlaug G. Adults and children processing music: an fMRI study. NeuroImage 2005;25:1068–1076. [PubMed: 15850725]

Koelsch S, Fritz T, Von Cramon DY, Muller K, Friederici AD. Investigating emotion with music: an fMRI study. Human Brain Mapping 2006;27:239–250. [PubMed: 16078183]

Koyama T, McHaffie JG, Laurienti PJ, Coghill RC. The subjective experience of pain: where expectations become reality. Proceedings of the National Academy of Science, USA 2005;102:12950–12955.

Lahav A, Saltzman E, Schlaug G. Action representation of sound: audiomotor recognition network while listening to newly acquired actions. Journal of Neuroscience 2007;27:308–314. [PubMed: 17215391]

Lascu DN, Zinkhan G. Consumer conformity: review and applications for marketing theory and practice. Journal of Marketing Theory & Practice 1999;7:1–12.

Levitin DJ, Menon V. Musical structure is processed in "language" areas of the brain: a possible role for Brodmann Area 47 in temporal coherence. NeuroImage 2003:20.

Montague PR, Berns GS. Neural economics and the biological substrates of valuation. Neuron 2002;36:265–284. [PubMed: 12383781]

Padoa-Schioppa C, Assad JA. Neurons in the orbitofrontal cortex encode economic value. Nature 2006;441:223–226. [PubMed: 16633341]

Peyron R, Laurent B, Garcia-Larrea L. Functional imaging of brain responses to pain. A review and meta-analysis. Neurophysiologic Clinics 2000;30:263–288.

Plassmann H, O'Doherty J, Shiv B, Rangel A. Marketing actions can modulate neural representations of experienced pleasantness. Proc Natl Acad Sci U S A 2008;105:1050–1054. [PubMed: 18195362]

Ploghaus A, Becerra L, Borras C, Borsook D. Neural circuitry underlying pain modulation: expectation, hypnosis, placebo. Trends in Cognitive Sciences 2003;7:197–200. [PubMed: 12757820]

Poldrack RA. Can cognitive processes be inferred from neuroimaging data? Trends in Cognitive Sciences 2006;10:59–63. [PubMed: 16406760]

Porro CA, Barardi P, Pagnoni G, Serafini M, Facchin P, Maieron M, Nichelli P. Does anticipation of pain affect cortical nociceptive systems? Journal of Neuroscience 2002;22:3206–3214. [PubMed: 11943821]

Preuschoff K, Bossaerts P, Quartz SR. Neural differentiation of expected reward and risk in human subcortical structures. Neuron 2006;51:381–390. [PubMed: 16880132]

Rangel A, Camerer C, Montague PR. A framework for studying the neurobiology of value-based decision making. Nature Reviews Neuroscience 2008;9:545–556.

Roesch MR, Taylor AR, Schoenbaum G. Encoding of time-discounted rewards in orbitofrontal cortex is independent of value representation. Neuron 2006;51:509–520. [PubMed: 16908415]

Rolls ET. The orbitofrontal cortex and reward. Cerebral Cortex 2000;10:284–294. [PubMed: 10731223]

Sanfey AG, Rilling JK, Aronson JA, Nystrom LE, Cohen JD. The neural basis of economic decision-making in the Ultimatum Game. Science 2004;300:1755–1758. [PubMed: 12805551]

Singer T, Seymour B, O'Doherty J, Kaube H, Dolan RJ, Frith CD. Empathy for pain involves the affective but not sensory components of pain. Science 2004;303:1157–1162. [PubMed: 14976305]

Slovic P. The construction of preference. American Psychologist 1995;50:364–371.

Spitzer M, Fischbacher U, Herrnberger B, Gron G, Fehr E. The neural signature of social norm compliance. Neuron 2007;56:185–196. [PubMed: 17920024]

Sridharan D, Levitin DJ, Chafe CH, Berger J, Menon V. Neural dynamics of event segmentation in music: converging evidence for dissociable ventral and dorsal networks. Neuron 2007;55:521–532. [PubMed: 17678862]

Steinberg L, Monahan KC. Age differences in resistance to peer influence. Developmental Psychology 2007;43:1531–1543. [PubMed: 18020830]

Tremblay L, Schultz W. Relative reward preference in primate orbitofrontal cortex. Nature 1999;398:704–708. [PubMed: 10227292]

Zatorre RJ, Chen JL, Penhume VB. When the brain plays music: auditory-motor interactions in music perception and production. Nature Reviews Neuroscience 2007;8:547–558.

NIH-PA Author Manuscript
NIH-PA Author Manuscript

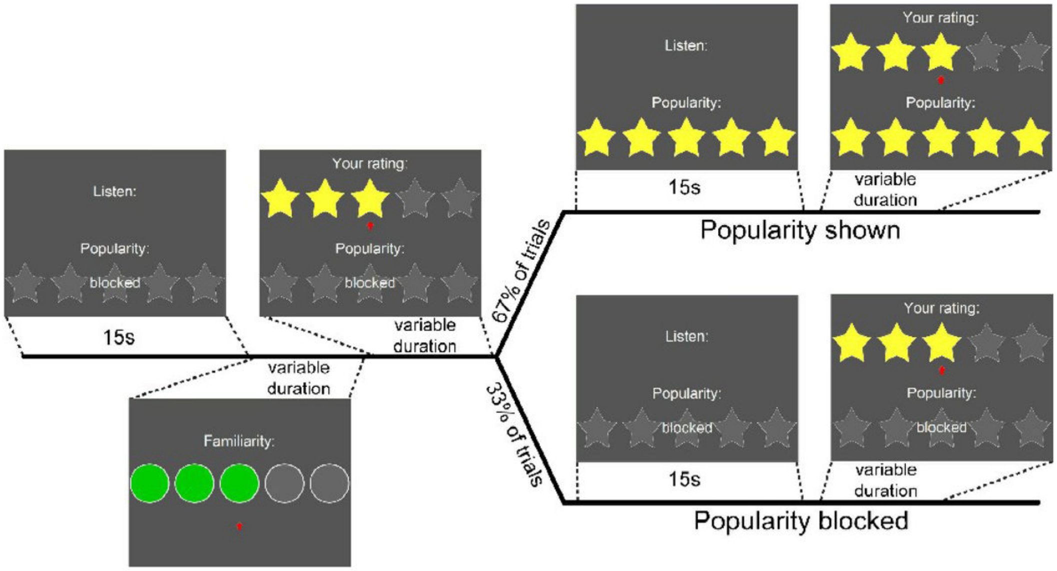

Figure 1.
Trial design. Each trial began with a 15-second clip from a song downloaded from MySpace.com. Following the clip, the participant rated the song for both familiarity and likability on a 5-star scale. The participant then heard the clip a second time, after which he rated the song again. There were a total of 60 trials. On 2/3 of the trials the popularity of the song was displayed during the second listen. On 1/3 of the trials, the popularity was not shown (blocked).

NIH-PA Author Manuscript
NIH-PA Author Manuscript

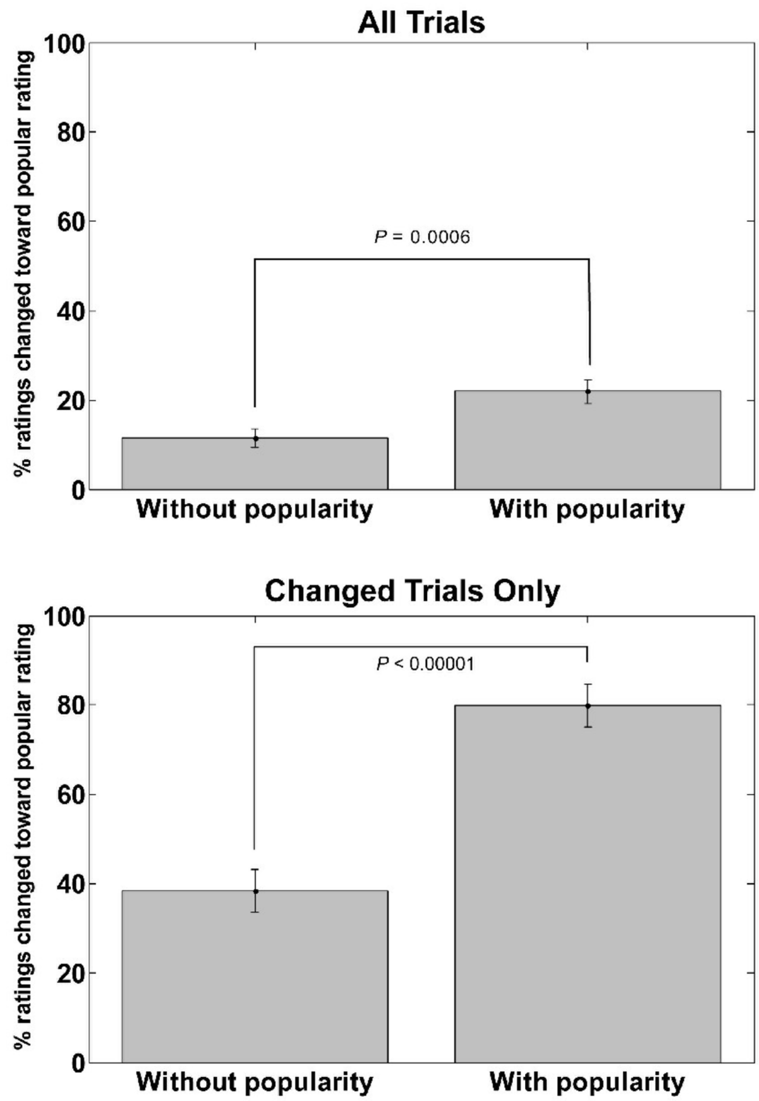

Figure 2.
Behavioral results. The popularity treatment had a significant effect on the percentage of trials in which a participant changed her likability rating. Without popularity information displayed, participants changed their ratings on 11.6% of the trials. With popularity shown, they changed their ratings 21.9% of the time (*top*, P=0.0006, paired t-test, 31 d.f.). As a fraction of the trials in which they changed their ratings, they changed in the direction of popular opinion 38.3% of the time when popularity was not shown versus 79.9% of the time when popularity was shown (*bottom*, P<0.00001).

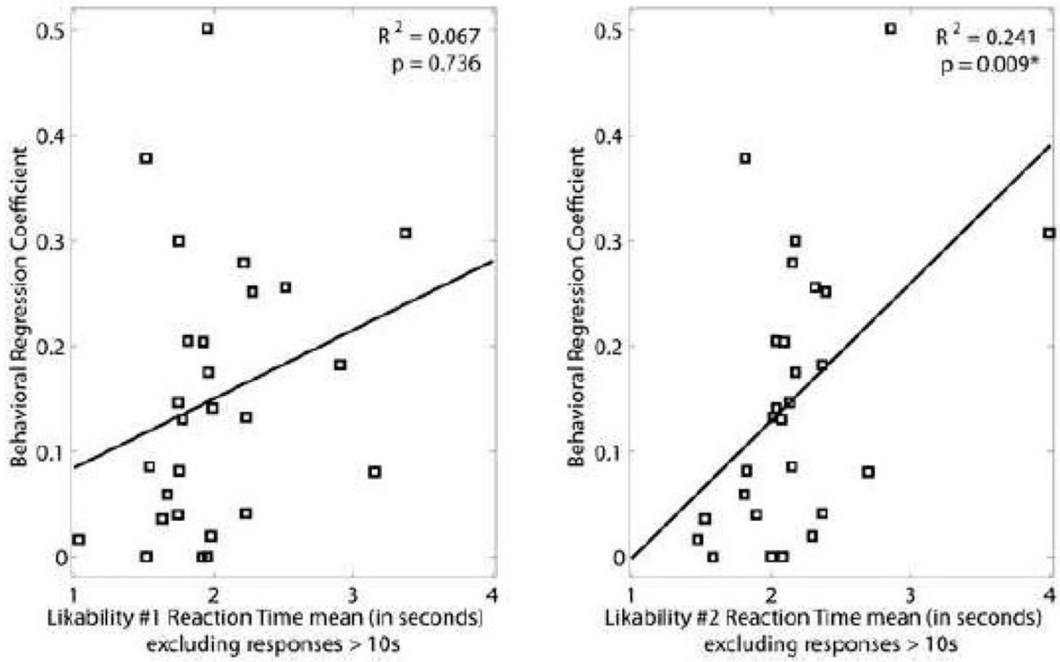

Figure 3.

Decision times for submitting likability rating vs. subjectwise sensitivity to popularity. We hypothesized that participants who were more sensitive to popularity would take longer to submit their ratings when popularity was present. There was no significant correlation between mean likability decision time and the subject's popularity sensitivity during the first listen (*left*), but there was a significant correlation during the second listen (*right*, $R^2 = 0.241$, P=0.009). Subjects who were more sensitive to popularity took longer to give their likability rating, but only during the second listen.

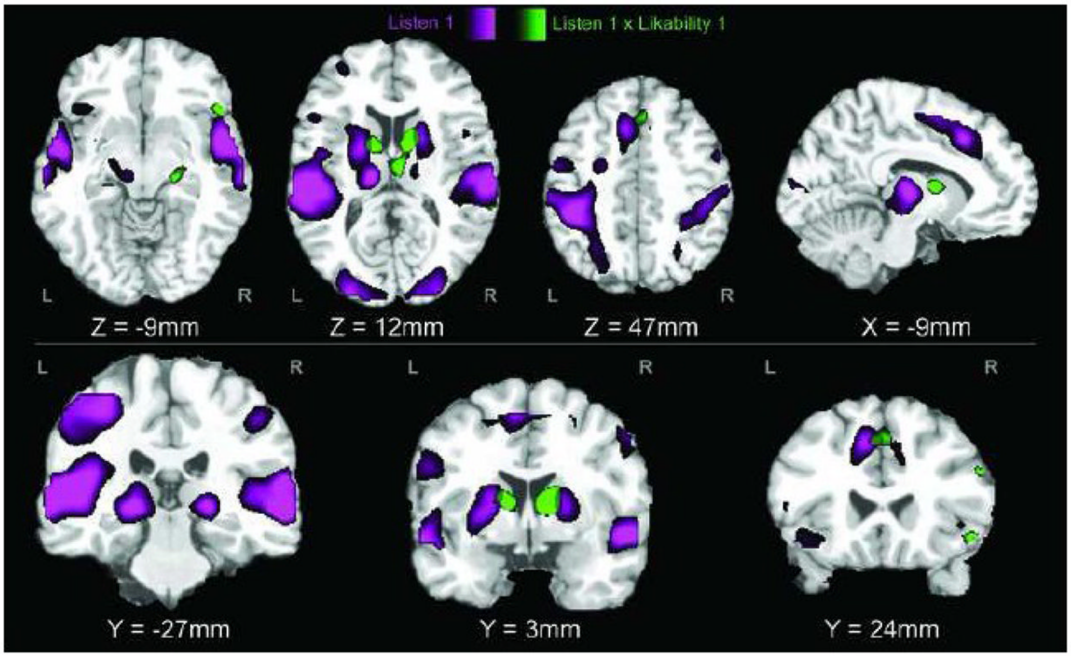

Figure 4.
Brain regions with significant activation during the 1st listen (*violet*) and regions with activation significant correlated with the subsequent likability rating (*green*) (all thresholds at P<0.001, k≥5). The main effect of listening revealed a broad network of activations, with the strongest activity in auditory cortex (bilateral superior and middle temporal gyri), sensory association areas (superior parietal cortex), thalamus, and prefrontal regions. These activations were consistent with auditory stimulation (the music) as well as visual stimulation (the rating screen). Positive correlations with the subsequent likability rating revealed a strong effect in bilateral dorsal caudate and right lateral prefrontal cortex (*green*).

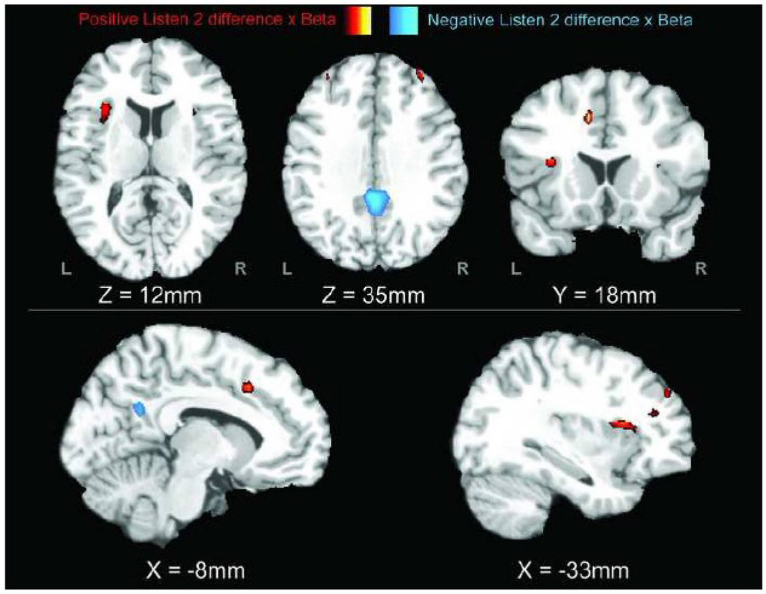

Figure 5.

Interaction between the subjectwise sensitivity to popularity and the effect of popularity information during the second listen (P<0.001, k≥5). The first-level contrast, representing the difference between popularity and no popularity during the second listen *(listen2pop – listen2nopop*), was examined for significant interactions with subjectwise popularity (β_j) in a second-level model. Regions in which the contrast difference was positively correlated with β_j included bilateral anterior insula, ACC/SMA, and frontal poles (*red/yellow*). Negative correlations with β_j were observed in PCC (*blue*).

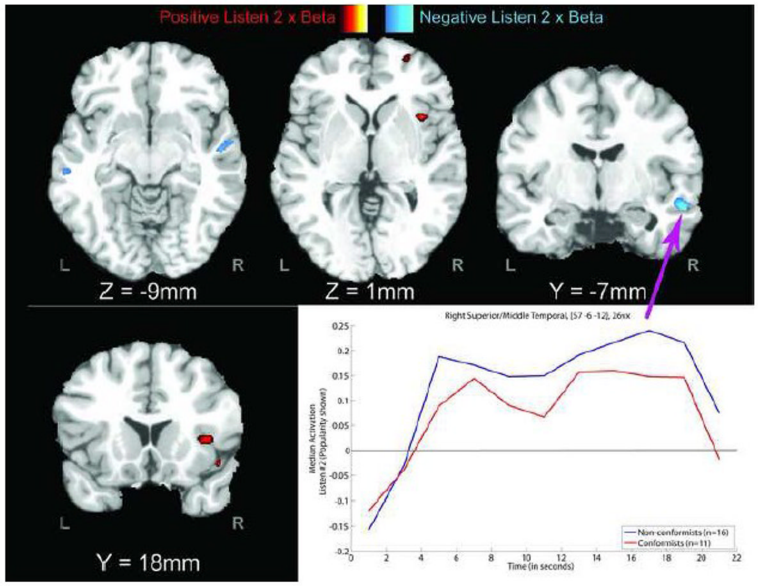

Figure 6.
Interaction between subjectwise sensitivity to popularity and the presence of popularity information during the second listen (P<0.001, k≥5). The first-level contrast, representing the effect of popularity during the second listen relative to the implicit baseline (main effect of *listen2pop*), was examined for significant interactions with subjectwise popularity (β_j) in a second-level model. Positive correlations were similar to that observed in the interaction of [*listen2pop* – *listen2nopop*] X β_j (figure 5). Negative correlations revealed significant interactions in bilateral middle temporal gyrus (blue). Extraction of timecourses during the second listen in these regions revealed lower levels of sustained activations during the song in the subjects who were sensitive to popularity (*red line, lower right*, split determined by kmeans clustering).

NIH-PA Author Manuscript

NIH-PA Author Manuscript

Table 1

Correlations of music popularity-sensitivity score with participant characteristics (N=32). The popularity score (β_j) was negatively correlated with age in months, total score on the Adolescent Risk Questionnaire (ARQ), and gambling for gains on the Harbaugh gambling task.

		Age (months)	**ARQ: PCA weighted, total**	**Harbaugh: %gambles on equal- EV gain trials**	**Harbaugh: %gambles on equal- EV loss trials**
Music: Popularity score	R	−0.407	−0.349	−0.356	0.119
	p	0.021*	0.050*	0.045*	0.516
Age (months)	R		0.655	0.126	−0.167
	p		<0.0001*	0.493	0.360
ARQ: PCA weighted, total	R			0.237	−0.254
	p			0.192	0.161
Harbaugh: % gambles on equal- EV gain trials	R				−0.238
	p				0.189

NIH-PA Author Manuscript
NIH-PA Author Manuscript

Table 2

Brain regions correlating with likability during the first listen (P<0.001 and cluster size ≥ 5).

		MNI			Talairach					
Label	**BA**	**x**	**y**	**z**	**x**	**y**	**z**	**T**	**Size**	**Correlation Direction**
Bilateral Caudate		12	6	9	12	6	8	6.23	197	Positive
R Inferior/Middle Frontal	9	57	21	27	56	22	24	5.12	17	Positive
R Inferior Frontal	47	51	24	−9	50	23	−9	4.29	12	Positive
R Sublobar/Parahippocamp		21	−15	−12	21	−15	−9	4.02	13	Positive
L Cingulate	32	−3	24	42	−3	25	37	3.99	35	Positive
R Superior Temporal	22	69	−39	12	68	−37	13	3.83	7	Positive
R Middle Temporal	21	57	−30	−3	56	−29	−1	3.68	6	Positive
L Supramarginal	40	−42	−51	36	−42	−48	36	4.45	10	Negative
R Middle Frontal		30	24	33	30	25	29	4.44	7	Negative
L Middle Occipital	37	−54	−69	3	−53	−67	6	4.31	10	Negative
R Supramarginal	40	54	−42	33	53	−39	32	4.23	50	Negative
L Insula	13	−45	−12	6	−45	−11	6	4.17	17	Negative
L Postcentral	2	−48	−24	30	−48	−22	29	4.12	19	Negative
R Postcentral	2	42	−24	33	42	−22	31	4.07	7	Negative
R Frontal	6	21	−6	57	21	−3	53	3.97	13	Negative
L Inferior Parietal	40	−57	−51	42	−56	−47	41	3.72	7	Negative

NIH-PA Author Manuscript

NIH-PA Author Manuscript

Table 3

Brain regions showing a significant correlation with popularity shown (*listen2pop*) and the covariate (*pop – lik1*) (P<0.001 and cluster size ≥ 5).

		MNI			Talairach					
Label	**BA**	**x**	**y**	**z**	**x**	**y**	**z**	**T**	**Size**	**Correlation Direction**
L Middle Occipital	19	−45	−78	6	−45	−75	9	3.82	31	Positive
R Middle Occipital		33	−75	3	33	−73	6	3.72	47	Positive
R Middle Frontal		42	39	−3	42	38	−4	4.15	49	Negative
R Superior Frontal	10	30	57	27	30	56	22	3.73	40	Negative
R Cingulate	9	6	27	36	6	28	32	3.52	52	Negative

NIH-PA Author Manuscript
NIH-PA Author Manuscript

Table 4

Brain regions showing a significant correlation with popularity shown (*listen2pop*) and the covariate |*pop* – *lik1*| (P<0.001 and cluster size ≥ 5).

		MNI			Talairach					
Label	**BA**	**x**	**y**	**z**	**x**	**y**	**z**	**T**	**Size**	**Correlation Direction**
L Medial Frontal	10	−3	57	18	−3	56	14	4.51	193	Positive
L Inferior Frontal	47	−54	21	0	−53	20	−1	4.14	74	Positive
R Inferior Frontal		51	33	−9	50	32	−9	3.72	38	Positive
L Inferior Parietal	25	−48	−36	36	−47	−33	35	5.19	174	Negative
L Precuneus		−12	−39	42	−12	−36	40	5.02	375	Negative
L Middle Temporal		−45	−75	18	−45	−72	20	4.40	188	Negative
R Precuneus		21	−63	24	21	−60	25	4.35	351	Negative
L Parahippocampal		−21	−42	−6	−21	−41	−3	4.25	45	Negative
R Insula	22	48	−3	−3	48	−3	−2	4.08	105	Negative

Table 5

Brain regions showing a significant correlation between (a) the difference in activation during the second listen between when popularity shown and not shown (*listen2pop* - *listen2nopop*) and (b) the subjectwise popularity-sensitivity score ($P<0.001$ and cluster size ≥ 5).

		MNI			Talairach					
Label	**BA**	**x**	**y**	**z**	**x**	**y**	**z**	**T**	**Size**	**Correlation Direction**
L Cingulate	32	−9	18	42	−9	19	38	4.47	7	Positive
R Superior Frontal	9	33	48	36	33	48	31	4.26	8	Positive
L Insula	13	−33	15	15	−33	15	13	4.12	24	Positive
L Superior Frontal	9	−33	45	36	−33	45	31	3.85	6	Positive
Bilateral Cingulate	31	0	−42	33	0	−39	32	4.99	195	Negative

Table 6

Brain regions showing a significant correlation between (a) the activation during the second listen with popularity shown (*listen2pop*) and (b) the subjectwise popularity-sensitivity score (P<0.001 and cluster size ≥ 5).

		MNI			Talairach					
Label	**BA**	**x**	**y**	**z**	**x**	**y**	**z**	**T**	**Size**	**Correlation Direction**
R Insula	13	39	15	3	39	15	2	4.58	20	Positive
R Superior Frontal	10	30	60	−3	30	58	−5	4.26	18	Positive
R Middle Temporal	21	57	−6	−12	56	−6	−10	5.09	26	Negative